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Research article

Mechanisms and risk of cumulative impacts to coastal ecosystem services: An expert elicitation approach

Gerald G. Singh [a, *], Jim Sinner [b], Joanne Ellis [b, c], Milind Kandlikar [a], Benjamin S. Halpern [d, e, f], Terre Satterfield [a], Kai M.A. Chan [a]

[a] Institute for Resources, Environment, and Sustainability, The University of British Columbia, Vancouver, Canada
[b] Cawthron Institute, Private Bag 2, Nelson, New Zealand
[c] Red Sea Research Centre, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
[d] National Center for Ecological Analysis and Synthesis, Santa Barbara, USA
[e] Bren School of Environmental Science & Management, UCSB, Santa Barbara, CA 93101 USA
[f] Silwood Park Campus, Imperial College London, Ascot, SL57PY, UK

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ABSTRACT

Coastal environments are some of the most populated on Earth, with greater pressures projected in the future. Managing coastal systems requires the consideration of multiple uses, which both benefit from and threaten multiple ecosystem services. Thus understanding the cumulative impacts of human activities on coastal ecosystem services would seem fundamental to management, yet there is no widely accepted approach for assessing these. This study trials an approach for understanding the cumulative impacts of anthropogenic change, focusing on Tasman and Golden Bays, New Zealand. Using an expert elicitation procedure, we collected information on three aspects of cumulative impacts: the importance and magnitude of impacts by various activities and stressors on ecosystem services, and the causal processes of impact on ecosystem services. We assessed impacts to four ecosystem service benefits — fisheries, shellfish aquaculture, marine recreation and existence value of biodiversity—addressing three main research questions: (1) how severe are cumulative impacts on ecosystem services (correspondingly, what potential is there for restoration)?; (2) are threats evenly distributed across activities and stressors, or do a few threats dominate?; (3) do prominent activities mainly operate through direct stressors, or do they often exacerbate other impacts? We found (1) that despite high uncertainty in the threat posed by individual stressors and impacts, total cumulative impact is consistently severe for all four ecosystem services. (2) A subset of drivers and stressors pose important threats across the ecosystem services explored, including climate change, commercial fishing, sedimentation and pollution. (3) Climate change and commercial fishing contribute to prominent indirect impacts across ecosystem services by exacerbating regional impacts, namely sedimentation and pollution. The prevalence and magnitude of these indirect, networked impacts highlights the need for approaches like this to understand mechanisms of impact, in order to develop strategies to manage them.

1. Introduction

Many human uses of coastal ecosystems degrade and convert coastal ecosystems through infrastructure development, resource extraction, tourism, and other human activities (Halpern et al., 2008a,b; Doney, 2010). People harvest and grow food from, recreate in, and transport goods through coastal systems. Coastal ecosystems are some of the most populated ecosystems on Earth, with half of the global population and three quarters of major cities within 60 km of a coastline (Kennish, 2002; UNEP, 2007, 2012). Future projections of human population and movement trends suggest that these figures will continue to rise, increasing the pressure on coastal environments. Coastal systems are being

* Corresponding author. Current address: Nippon Foundation Nereus Program, Institute for the Oceans and Fisheries, The University of British Columbia, Vancouver, Canada.
E-mail addresses: g.singh@oceans.ubc.ca (G.G. Singh), Jim.Sinner@cawthron.org.nz (J. Sinner), joanne.ellis@kaust.edu.sa (J. Ellis), mkandlikar@ires.ubc.ca (M. Kandlikar), halpern@nceas.ucsb.edu (B.S. Halpern), terre.satterfield@ires.ubc.ca (T. Satterfield), kaichan@ires.ubc.ca (K.M.A. Chan).

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converted to “use” environments and are projected to experience greater stress (Kennish, 2002) as some projections show that 6 billion people will live in coastal areas by 2025 (UNEP, 2007). Given the current and future context, there is a need to understand how human activities and stressors impact ecosystems and the services they provide.

The concept of ecosystem services has been used to understand human uses and values associated with many environments (Carpenter et al., 2009; Chan and Ruckelshaus, 2010; Kareiva et al., 2011; Queiroz et al., 2015). Most ecosystem service research to date, through mapping and valuation, emphasizes the benefits humans derive from the natural environment (De Groot et al., 2002; Chan et al., 2006; Costanza et al., 2014). The analysis of ecosystem services includes three steps (Tallis et al., 2012): the supply (production of services by the biophysical environment), the service (the service actually used by people), and the value (the preferences for different services). All of these may be affected by human activities. Thus, understanding risk to ecosystem services as the relationship between people and the environment (including human influence on the environment, as well as the environment's influence on people) is key to a balanced treatment of management concerns (Raymond et al., 2013). Effective management would explicitly address how and why valued aspects of the environment are at risk, including ecosystem services at risk from cumulative impacts of interacting local and global stressors (Allan et al., 2013).

Researchers have advanced various frameworks to study anthropogenic effects on coastal systems, but few address ecosystem services specifically. Some researchers use a mapping framework with an additive cumulative impacts model to map the distribution of biological communities and human impact in response to human pressures on coastal environments (Rodrigues et al., 2004). Other frameworks outline the mechanistic processes of impact, linking human activities and other drivers of change with stressors – the processes that cause impact – with species and ecosystems (derived from the DPSIR approach, Curtin and Prellezo, 2010). These research frameworks on environmental impacts have, however, rarely linked process (mechanism) with the size of impact, instead focusing on *either* process *or* impact.

To prioritize management actions based on delivery of ecosystem services, tools are needed to identify how human drivers impact ecosystem services (Cook et al., 2014). One response to this need is to focus on the drivers of change (human activities and global forces – such as climate change – that instigate impacts, henceforth referred to as “drivers”), and stressors (the processes by which drivers cause impact, such as through increased temperatures) that have the greatest impact on management goals. Conversely, failing to understand the severity of cumulative impact, as well as the mechanistic pathway of impact, can lead to misallocated management efforts (Brown et al., 2013; Cook et al., 2014). These considerations underline the importance of linking pathways of effects (the processes by which human and large scale environmental processes contribute to impacts) to the most prominent impacts.

Research on cumulative impacts faces the ever-present problem of data paucity, and this is especially true for impacts to ecosystem services. In many cases data are non-existent. In such cases the best (often only) option is to rely on expert elicitation (Burgman, 2005; Altman et al., 2010). Expert data is often time-integrated knowledge, and can stand in for long-term field data that can be prohibitively costly to acquire (Burgman et al., 2011; Martin et al., 2012; McBride and Burgman, 2012; Morgan, 2014). Experts can also use their experience and acquired instinct to interpolate or extrapolate measures of impact when there are no clear metrics to measure in the field (Burgman, 2005; Teck et al., 2010; Sagoff, 2011; Cook et al., 2014). Expert elicitation as a way to acquire information has unique strengths and weaknesses, as experts can assess tradeoffs and uncertainties (and provide a logical defense of their judgements) in ways that are not possible otherwise (Kandlikar et al., 2007), but relying on expert judgement may introduce extra uncertainty through diverse linguistic and epistemic understandings of “impact” (Regan et al., 2002). Expert judgment is a collection of various uncertainties and mixed biases regarding what matters for impact, and multiple experts may not translate the problem in the same way, but a well-designed elicitation process can help alleviate some of these challenges to analysis (Martin et al., 2012; Morgan, 2014).

We use Tasman and Golden Bays, New Zealand as a case study to explore cumulative impacts on ecosystem services by using expert elicitation to identify which ecosystem services are at risk by what human activities in what ways. We define cumulative impacts as the combined total effect of multiple effects that limit the ability of people to enjoy ecosystem services. Specifically, we ask, 1) how severe are cumulative impacts on ecosystem services? 2) are threats to ecosystem services evenly distributed across activities and stressors, or do few dominate? 3) Do prominent activities mainly operate through direct stressors, or do they often exacerbate other impacts?

2. Methods

2.1. Tasman and Golden Bays

Tasman and Golden Bays are situated at the northern end of the South Island of New Zealand (Fig. 1). We focus on impacts to fisheries, shellfish aquaculture, marine recreation, and existence values of biodiversity because these are all primary uses/benefits in the bays and have been for decades, with available experts to provide useful insights. These uses and benefits are also common to coastal areas around the world, meaning that insights generated here may have some applicability elsewhere.

Tasman and Golden Bays have a history of human activities that have altered the physical environment. Trawl fisheries have historically contributed to the transformation of the benthic habitat in these areas from a complex 3-dimensional environment with thick mussel beds and oyster reefs to a flat silty bottom (Handley, 2006). The terrestrial catchments of the bays have also witnessed a significant increase in urban, agricultural (sheep and beef, horticulture and dairy) and forestry activity since European settlement in the latter half of the nineteenth century (Handley, 2006).

2.2. Expert elicitation

In Tasman and Golden Bays, we quantified the risks to the four ecosystem services as follows. The elicitation procedure followed an iterative procedure focused on training and feedback for experts to minimize uncertainty in communicating directions to experts (McBride and Burgman, 2012; Morgan, 2014). We assembled a team of experts for each service based on their experience researching and working in the case study areas (often for over a decade), and used a survey instrument to provide a ranked list of drivers and stressors acting upon each service (Table S1). We then interviewed each expert individually to derive impact scores and pathways for each designated activity or stressor, characterizing uncertainty parameters for each resulting in ‘impact profiles’. We asked experts to provide a relative impact score (with uncertainty) from 0 to 1, with 0 representing the ecosystem service as unimpacted by the stressor and 1 rendering the ecosystem service unavailable for human benefit. We then invited all experts to a facilitated group workshop, in which experts exchanged views about their impact scores and pathways, and again provided impact